FOLLOW UP EVALUATION OF DESIGN CHANGES TO A HOUSEBOAT GENERATOR EXHAUST STACK SYSTEM

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REPORT DATE:
July 2004

REPORT NO.:
EPHB 171-34a2

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SIC Code:	N/A
Survey Dates:	August 27, 2003
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INTRODUCTION

On April 27th, 2004, National Institute for Occupational Safety and Health (NIOSH) researchers conducted a follow-up evaluation of an exhaust stack designed to reduce carbon monoxide (CO) emissions and prevent exposures on houseboats at Sumerset Acquisitions LLC in Somerset, Kentucky. This work was conducted to evaluate permanent design changes that were made to the Sumerset stack since the August 2003 CO evaluation documented in the NIOSH report titled, "An evaluation of factors that might influence exhaust stack performance to prevent carbon monoxide poisonings from houseboat generator exhaust."(1) Although the exhaust stacks evaluated during the August 2003 NIOSH study performed well, the initial design included several factors that influenced the stack performance. The factors included small pipe diameters, long runs from the water separator to the end of the stack, numerous bends, and horizontal runs. Those factors created high static pressure in the stack that did not allow the system to function properly and allow all of the exhaust gases to travel up through the stack to a non-occupied area above the top deck. Instead, the high pressure in the previous stack designs caused some of the exhaust gases to be forced out the water outlet near the water level at the side of the boat. Following the NIOSH August 2003 evaluation, Sumerset made several permanent exhaust stack design changes to alleviate the static pressure problems. This report provides a brief description of the design changes, methods, results, and conclusions from the follow-up evaluation.

METHODS

CO measurements were collected on a 2004 model Sumerset Acquisitions LLC (Somerset, KY). The houseboat had a gasoline-powered generator connected to a stack that exhausted the CO in a non-occupied area above the top deck on the stern, port-side of the boat. Data were collected to evaluate the performance of the exhaust stack to reduce CO concentrations on the houseboat. The evaluation took place in the morning on a test pond at the Sumerset factory.

Description of the Evaluated Houseboat and Engineering Control

A 2004 Sumerset houseboat with rear port stack and Combo-Sep muffler/gas/water separator was tested on Sumerset's test pond. This houseboat had a 20 kW Westerbeke, gasoline-powered generator (model BEG). All parts of the system that contained lake water were connected by flexible wet marine exhaust hose. The aluminum exhaust stack was also connected to the separator by this same marine hose. The 2-inch inside diameter exhaust stack was approximately 396 inches long, of which 193 inches were vertically run. All non-vertical runs were slightly inclined to eliminate water traps. The stack extended to approximately 7 feet above the top deck at approximately 30° from the vertical axis off of the rear port corner of the boat in a non-occupied area. The system tested had minimal diameter changes at the connection points and had only two 90 degree bends in the stack. The stack design changes made by Sumerset since the NIOSH August 2003 study were intended to improve the performance of the system and prevented the exhaust gases from exiting the water outlet. Some of those design improvements included increasing the inner diameter of the stack from 1.75 inches to 2 inches, eliminating a 90° and a 180° bend, eliminating two horizontal runs, and decreasing the overall length from the water separator to the end of the stack while maintaining the same stack height above the top deck. Although some pressure reduction was achieved by eliminating bends and reducing length, testing on the same system conducted by University of Cincinnati senior design students showed that increasing the diameter accounted for most of the pressure reductions. Detailed data showing pressure reductions from various diameters, lengths, and bends of the Sumerset exhaust stack can be found in a University of Cincinnati mechanical engineering design clinic report.(2)

Description of the Evaluation Equipment

CO concentrations were measured at various locations on the houseboat using ToxiUltra Atmospheric Monitors (Biometrics, Inc.) with CO sensors. ToxiUltra CO monitors were calibrated before and after use according to the manufacturer's recommendations. These monitors are direct-reading instruments with data logging capabilities. The instruments were operated in the passive diffusion mode with a 15-30 second sampling interval. The instruments have a nominal range from 0 ppm to 999 ppm.

Description of Procedures

The evaluation was performed during the morning on the test pond at Sumerset Acquisitions LLC in Somerset, KY. The test was performed for two conditions: testing with no load on the generator, and testing with a load on the generator of approximately 35 Amps on each leg. CO measurements were taken every 30 seconds with the direct reading instrumentation for approximately 40 minutes under each loading condition. The ToxiUltra real-time monitors were placed in ten locations on the lower and upper decks of the houseboat. The monitors were placed at the ten locations to provide representative samples of occupied areas on the houseboats. Several monitors were placed on the swim platform because people commonly enter and exit the water via this structure.

RESULTS

Real-time CO monitoring results on the upper and lower deck of the houseboat are shown in Figures 1 and 2. Tables I and II contain summary statistics of the real time CO monitoring data for both generator load conditions. The highest peak CO level measured that day on the top deck was 21 ppm with the generator under load. The highest peak CO value measured on the lower deck was 3 ppm for both generator load conditions. The highest average CO concentration of 6.7 ppm was measured with no load on the generator at a location on the top deck near the bar. The highest average concentration of CO measured on the lower deck was 2.0 ppm at a location near the stairs with no load on the generator. The peak values were well below the NIOSH ceiling of 200 ppm and below the NIOSH recommended exposure limit (REL)(3) of 35 ppm. The average concentrations are below the World Health Organizations (WHO) standards(4) and the Environmental Protection Agency (EPA) standards(5) of 9 ppm for an 8-hour time-weighted average (TWA) exposure. Although wind data was not collected during this limited evaluation, wind velocities were estimated to be high. The boat was oriented so that the direction of the wind passed from the back of the boat to the front.

CONCLUSIONS AND RECOMMENDATIONS

1. From the results of this follow up evaluation and previous NIOSH studies of well designed exhaust stacks, the CO hazard to swimmers and occupants on houseboats that have gasoline-

powered generators can be greatly reduced by retrofitting engineering control systems such as the exhaust stack connected to the generators. Previous NIOSH studies have shown that an exhaust stack (that releases the CO and other emissions high above the upper deck of the houseboat in non-occupied areas) allows the contaminants to diffuse and dissipate into the atmosphere away from boat occupants.[6] As technology for marine generators continues to develop, other types of engineering controls may play an important roll in reducing CO concentrations on houseboats by reducing the emissions at the source. However, at the time of this evaluation, the vertical exhaust stack is the only available proven technology for reliably reducing concentrations of CO on houseboats. As new technologies for emissions controls become available, the safest option will be to combine the use of those new technologies with a well designed exhaust stack.

2. Manufacturers/owners/users of houseboats that have gasoline-powered generators equipped with exhaust stacks should ensure that they are designed properly, installed correctly, and operating as intended. The most important parameter to a properly designed exhaust stack is the inside diameter of the pipe. A small increase in the inside diameter from 1.75 inches to 2 inches accounted for a large percentage of the static pressure reduction in the exhaust stack on the Sumerset houseboat. The pressure reduction was necessary for the system to operate properly and prevented exhaust gases from exiting through the water outlet. Anyone designing or installing an exhaust stack on a houseboat generator should pay special attention to the balance of flow of water and air though the system and design the stack with a large enough diameter to eliminate restrictions to flow.

Table I: No generator load summary statistics of ten real-time sampling monitors

Monitor Location (no load)	Mean (ppm)	Std Dev	n	Peak (ppm)
Top deck (back)	1.2	0.4	83	2
Lower deck (near stairs)	2.0	0.4	81	3
Top deck (center)	2.0	1.5	83	8.5
Lower deck (center swim platform)	0.9	0.3	80	2
Top deck (near bar)	6.7	3.5	83	16
Lower deck (port swim platform)	1.2	0.4	80	2
Lower deck (starboard swim platform)	1.0	0.3	81	2
Top deck (starboard stern)	1.1	0.4	83	2
Top deck (near stack)	1.3	0.5	83	2
Lower deck (slide glass door)	0.7	0.5	77	2

n = sample size

Table II: With generator load summary statistics of ten real-time sampling monitors

Monitor Location (with load)	Mean (ppm)	Std Dev	n	Peak (ppm)
Top deck (back)	1.0	0.4	83	2
Lower deck (near stairs)	1.8	0.4	81	3
Top deck (center)	1.2	1.0	83	6.2
Lower deck (center swim platform)	0.8	0.5	80	2
Top deck (near bar)	5.0	4.4	83	21
Lower deck (port swim platform)	1.1	0.3	80	2
Lower deck (starboard swim platform)	0.8	0.4	81	1
Top deck (starboard stern)	0.9	0.4	83	2
Top deck (near stack)	1.1	0.4	83	2
Lower deck (slide glass door)	0.6	0.5	77	1

n = sample size

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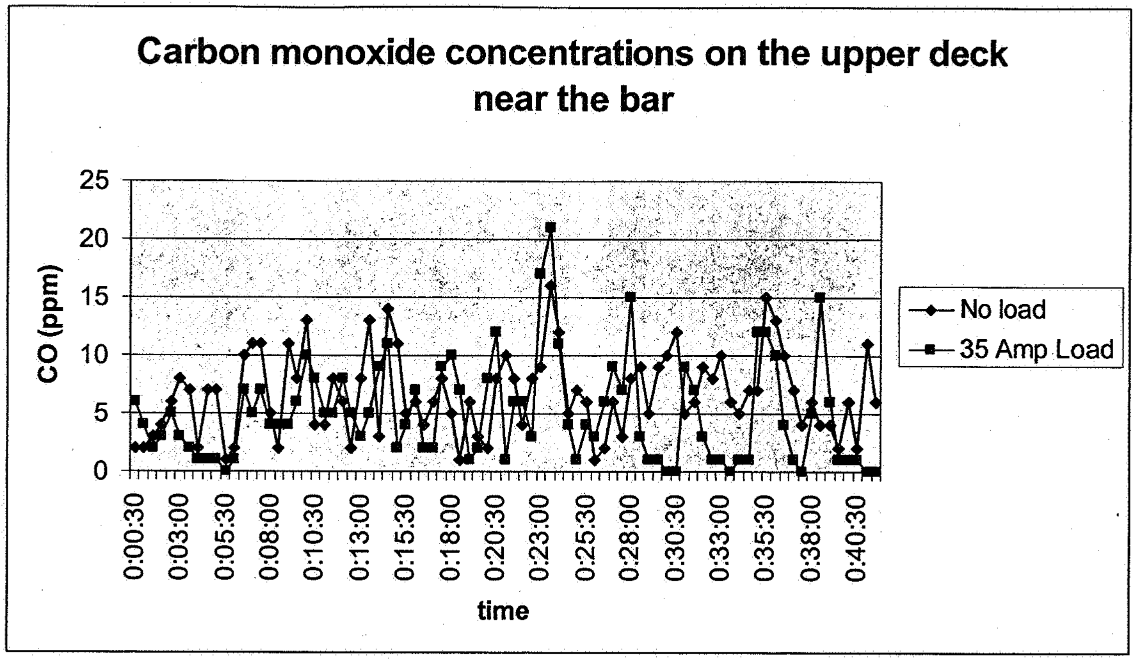

Figure 1: Carbon monoxide concentrations on the upper deck near the bar.

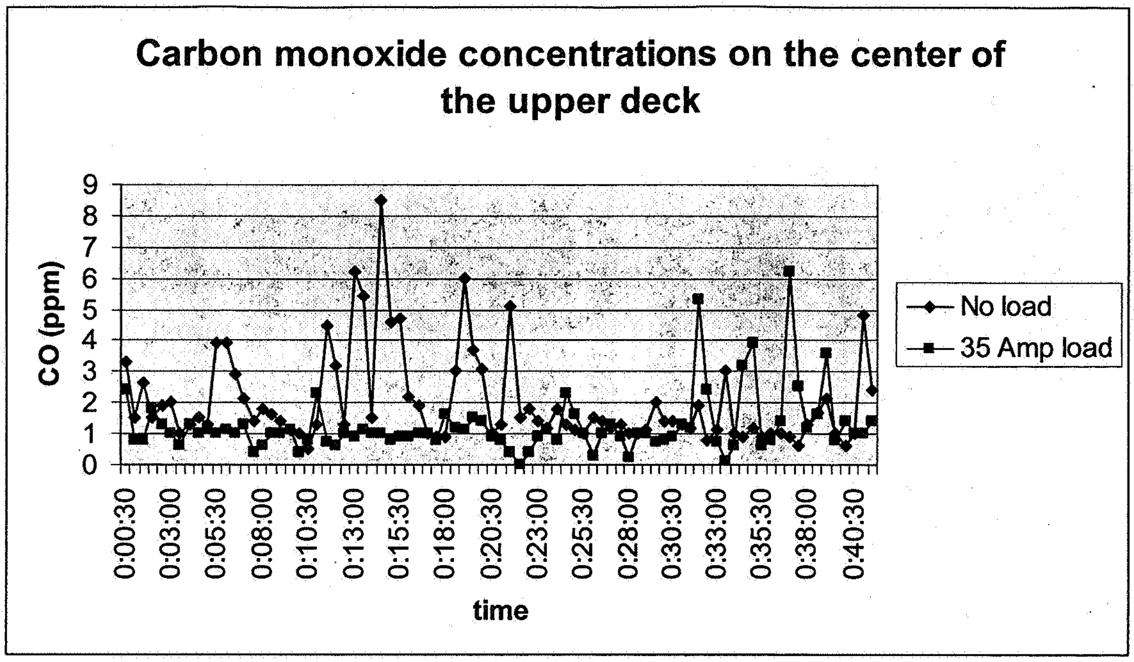

Figure 2: Carbon monoxide concentrations on the center of the upper deck.